Introduction

Pacific salmon have disappeared from approximately 40% of their historical breeding ranges in Washington, Oregon, Idaho, and California over the last century, and many remaining populations are severely depressed in areas where they were formerly abundant (NRC 1996). As a result of these declines a number of Pacific salmon stocks have been designated as threatened or endangered under the Endangered Species Act. Recently, the National Marine Fisheries Service listed the Puget Sound chinook (*Oncorhynchus tshawytscha*) as threatened.

Protection and rehabilitation of freshwater habitat and associated watershed processes are critical to conservation and restoration of Pacific salmon (NRC 1996). There are a number of small diversions and dams that block migration of adult salmon in the Pacific Northwest: barrier removal or installation of passage facilities at these structures will likely be an important measure in restoring access to freshwater habitat. The city of Seattle's Habitat Conservation Plan (HCP) for the Cedar River Watershed proposes to install a fish ladder at the Landsburg Diversion Dam, located on the Cedar River mainstem. This diversion has blocked anadromous fish migration to approximately 27 km of mainstem and tributary habitat for almost 90 years, and has likely resulted in a significant reduction in the amount of marine-derived nutrients and organic matter delivered to the watershed above Landsburg. It has been shown in other studies that salmon carcasses provide important nutrient subsidies to their natal streams and the surrounding terrestrial ecosystem (Bilby et al. 1996, Willson et al. 1998). In addition, resident salmonids in the uppermost Cedar River watershed have been isolated from anadromous salmonids; there are likely to be ecological effects (e.g., competition, predation) on these resident fishes resulting from the return of anadromous forms above Landsburg.

The goals of this project are to understand the effects anadromous fish have on aquatic (e.g., surface water nutrient chemistry) and terrestrial ecosystem productivity above the Landsburg Diversion Dam and to gain a better understanding of demographic processes that occur in salmon populations during recolonization of unoccupied habitat. The specific aims of this research are:

1) To identify habitat characteristics of the Cedar River mainstem above Landsburg and two tributaries, Rock and Taylor Creek;
2) To establish baseline conditions for surface water nutrient chemistry and and isotopic ratios of carbon and nitrogen in terrestrial and stream biota; and
3) To establish baseline conditions for populations of resident fishes in the Cedar River mainstem and Taylor and Rock Creeks.

Materials and Methods

Stream habitat inventory

A habitat inventory of the Cedar River was conducted during the period 26 July - 22 August 2000. The habitat inventory included the Lower Cedar River from Landsburg dam to Cedar River Falls, including three major tributaries (Rock, Taylor and Williams Creeks). The mainstem was divided into nine reaches based on gradient, confinement, and tributary junctions using topographic maps (Montgomery et al. 1999), and a video that scanned the Cedar River from Renton to Cedar Falls (Figure 1, Appendix 1). Rock Creek was divided into six reaches and Williams Creek was divided into three reaches, also based on gradient (Appendix 2). Taylor Creek was divided into two reaches with the upstream reach serving as a reference site as it was above a barrier to anadromous salmonids.

All habitat types were classified as riffles, pools, flatwaters, step pools or cascades based on criteria modified from Bisson et al. (1988). In each habitat we: (1) measured the length of each habitat unit to the nearest meter with a hip chain or by pacing; (2) estimated wetted width of each unit using a rangefinder or a tape measure; (3) counted the number of pieces of woody debris that were in the active channel within three size categories (LWD $\geq$ 50 cm in diameter and $\geq$ 3 m long; MWD $\geq$ 20 cm in diameter and $\geq$ 2 m and $\leq$ 3 m long; SWD $\geq$ 10 cm in diameter and $\geq$ 1 m and $\leq$ 2 m long); (4) visually estimated dominant and subdominant substrate types in each unit (sand $\leq$ 2 mm in diameter; gravel $\geq$ 2 mm and $\leq$ 64 mm; cobble $\geq$ 64 mm and $\leq$ 256 mm; boulder $\geq$ 256 mm); and (4) measured maximum depth and tail-out depth of each pool to the nearest cm using a graduated rod.

Fish populations

Counts of resident fish were conducted on the Cedar River, Taylor Creek and Rock Creek. Sites were chosen randomly from habitat units within each reach and habitat type strata mapped during the habitat survey (Appendix 3). Each site consisted of a single habitat unit; the entire unit was snorkeled except in cases where units were too large or dangerous and were therefore subsampled. One to four observers (depending on stream width) entered the habitat unit at the downstream end and proceeded upstream through each site, counting and recording species and size classes of all fish encountered. Resident salmonids (rainbow or cutthroat trout) were divided into three size classes (fry $\leq$ 80 mm in length; 1+ $\geq$ 81 and $\leq$120 mm, 2+ $\geq$121 and $\leq$ 200 mm; and > 2+ $\geq$ 201 mm). Sculpins (*Cottus* sp.) were also counted.

Estimates of fish population size were obtained at a subset of the snorkeled sites by electrofishing (Appendix 3). A two to four person crew completed three electrofishing passes at each site using a Smith-Root backpack electrofisher operating at 300-500 volts DC. All sites were sampled between 10:00 – 15:00. Sites were completely enclosed using 10 mm stretched-mesh seines before electrofishing to ensure population closure; nets were installed as quickly as possible to minimize disturbance to fish. In some cases, primarily at mainstem sites, only a part of the unit was sampled. All fish captured were anesthetized (MS-222), measured (fork length to the nearest mm), weighed (nearest 0.1 g), and kept in live baskets in the stream until electrofishing was completed, when they were released alive near their point of capture. The pelvic fin of all salmonids > 10 mm was clipped according to the location of their capture (mainstem - right pelvic; Rock or Taylor creeks - left pelvic). The number of fish captured at all sites was too low to produce meaningful removal estimates of population size, and population estimates were calculated as the sum of all fish caught.

Water quality sampling

Monthly collections of river water were taken beginning in June of 2000. Sites were selected to capture inputs of materials from tributaries; to provide reference sites (i.e., sites above a barrier to anadromous fish); and to overlap different reaches along the Cedar. Currently, we are collecting water from 15 sites (Figure 2, Appendix 4). Samples were collected according to the methods determined by Seattle Public Utility's (SPU's) water quality laboratory. Samples were immediately placed on ice and deposited at SPU's water quality laboratory where they were analyzed for total (unfiltered sample) phosphorus and nitrogen; dissolved phosphate; dissolved nitrate + nitrite; total organic carbon; alkalinity; conductivity; and turbidity. Water temperature and pH were measured and recorded in the field.

Stable isotopes of the riparian and aquatic food web

To establish baseline levels of the stable isotopes of carbon and nitrogen, we collected tissue of riparian vegetation (western red cedar, vine maple, and salmonberry), stream periphyton, aquatic insects (4 functional feeding groups: predators, grazers, detritivores, and collector-filterers), and fish (fry; 1 and 2+ salmonids; and sculpins). Sample sites were chosen based on habitat surveys; proximity to water chemistry sampling sites; and barriers to anadromous fish. Three sites were chosen on the Cedar River mainstem: RM 26 and RM 31; Rock Creek upstream of the 40 bridge; and Taylor Creek at the mouth of the Cedar and at the Taylor Creek USGS gauge which is above a barrier to anadromous fish. Tissues were collected in October 2000.

Periphyton was scraped from five randomly selected rocks for each location and stored in plastic bottles on ice until they were frozen. Invertebrates were collected using a Hess sampler with a 250 micron mesh net. Fish were collected by angling and electroshocking. Riparian foliage was collected from the dominant riparian vegetation; cedar, salmonberry, and maple. All samples were frozen immediately until they were dried and ground. Dorsal muscle tissue was taken from sacrificed fish.

Results

Stream habitat

The total habitat area accessible to salmonids in the mainstem Cedar between Landsburg and Cedar Falls was 405,360 m^2 (Table 1). Riffles made up the highest proportion (35%) of the total area, followed by step pools (30%), flatwaters (26%), pools (8%), and cascades (1%) (see Appendix 5 for pictures of different habitat types). The proportion of the area that was made up by the different habitat types was highly variable among reaches. More than half of the area of reaches 3, 5, and 7 was step pool habitat, while half of the area of reaches 2 and 8 was riffle. The proportion of the area made up of pools varied from 2-27%; pools made up 20% or more of the area of reaches 4 and 8 only. Pools were particularly rare (# 2% by area) in the lower three reaches of the mainstem. Flatwater habitat was most abundant in reach 1, probably due to the effects of the diversion dam; flatwater habitat was relatively rare in the upper reaches (e. g., the canyon reach) of the mainstem. Cascade habitat was found only in reaches 8 and 9. Mainstem side channels made up an additional 8624 m^2 of habitat in the Cedar; individual habitat units were not classified within side channels. The area of side channel habitat was low in the lower reaches (i.e., 151, 128, and 78 m^2 in reach 1, 2 and 4, respectively) and higher in reach 3 (455 m^2) and reaches 5-8 (approximately 500 m^2). No side channel habitat was measured in reach 9.

An additional 78,307 m^2 of stream habitat was measured in the tributaries to the mainstem Cedar (Table 2), although this does not represent the total available habitat because a section of Reach 4 of Rock Creek was not measured due to the presence of large beaver ponds that made habitat measurement logistically difficult. In the tributaries, pools generally made up a greater proportion of the area compared to the mainstem, but this varied among tributary reaches. The highest proportion of pool habitat (64%) was found in Reach 4 of Rock Creek; this was likely due to the presence of beaver dams. Step pool habitat was present only in the lower reach of Taylor Creek. Cascades were relatively rare in general, but made up a large proportion (42%) of the habitat in Williams Creek. Riffles made up more than half of the habitat of Rock and Taylor creeks, but only 37% of Williams Creek. A total of 2641 m^2 of tributary side channel habitat was measured (Rock – 2097 m^2; Taylor – 189 m^2; Williams – 355 m^2).

Although pools made up only 20% of the habitat area in the mainstem Cedar, they were numerically the most common habitat type, followed by riffles (Table 3). Pools were also the most abundant habitat type on tributaries (Table 4). Pool spacing in the mainstem (Table 5) and tributaries (Table 6) ranged from 3.6-17.9 channel widths per pool and varied widely within and among streams.

There were no significant differences among habitat types in the mainstem Cedar River (Table 7) or Taylor Creek (Table 8) in the number of pieces of woody debris (all size classes) per kilometer. In Rock Creek, cascades supported significantly more LWD than other habitats, and pools contained significantly more SWD (Table 9). In Williams Creek, pools supported more MWD than other habitat types; there were no significant differences among habitat types in LWD or SWD in Williams Creek (Table 10).

There were significant differences among reaches of the mainstem Cedar in the linear density (pieces/km) of woody debris of all classes (Table 11). Reach 6 had significantly higher counts of woody debris of all size classes than all other reaches, while reaches 3, 8, and 9 supported low numbers of all size classes. In Rock Creek, reach 1 supported a significantly higher linear density of LWD, while reach 6 had the highest density of MWD; there were no significant differences in SWD among reaches (Table 12). At Taylor Creek, there were no significant differences among reaches in the density of any woody debris size classes. In Williams Creek, reach 1 supported a higher linear density of SWD than the other two reaches; there were no significant differences among reaches in LWD or MWD. Overall, Rock Creek supported a significantly higher linear density of wood debris of all size classes than the mainstem or other tributaries, and the Cedar mainstem consistently supported the lowest (Table 13).

Fish populations

Estimates of salmonid density (all based on snorkel estimates) for the Cedar River generally increased from downstream to upstream with highest total densities recorded at reach 6 (0.11 per m^2) and reach 9 (0.13 per m^2) with lowest total densities at reach 2 (0.02 per m^2) (Figure 2a, Table 14). Highest salmonid densities were observed in pool (total density = 0.09 per m^2) and step-pool (0.08 per m^2) habitat, whereas riffles supported the lowest density (0.03 per m^2) (Figure 2b, Table 16).

Similar to the mainstem, salmonid density (based on electroshocking) at Rock Creek was greatest at upstream reaches (Figure 3a, Table 15). Total densities in reach 5 and 6 (0.40 per m^2) were approximately three times higher than reach 1. No estimates were obtained from reach 4, as this was the large beaver complex, which made obtaining reliable estimates logistically difficult. Pools (0.29 per m^2) supported approximately double the density of salmonids as riffles (0.12 per m^2) and cascades (0.16 per m^2) (Figure 2b, Table 16). Two reaches were surveyed on Taylor Creek (all snorkel estimates), with both reaches supporting approximately the same number of salmonids (0.04 per m^2) (Figure 4). Rock Creek supported the greatest density of salmonids for streams surveyed (Figure 5). For example, trout fry density was 3 to 11 times greater at Rock Creek compared to Taylor Creek and the Cedar River mainstem. The negative relationship between channel width and trout density provides further evidence that trout densities were higher in the smaller channels (Figure 6).

In general, snorkeling was a more efficient method of estimating salmonid abundance on the Cedar River mainstem (Figure 7a), especially in pools (Figure 7b), and Taylor Creek (Figure 5). Snorkel estimates of total salmonid density in the Cedar River were two to three times greater in reach 7 and 8, and four times greater in pools compared to estimates from electroshocking. Electroshocking on the mainstem and Taylor Creek provided particularly low estimates for larger fish (i.e., 1 and 2+ size classes) compared to snorkeling: we recorded no individuals in these size classes using electroshocking. In contrast, electroshocking in Rock Creek generated higher total densities in pools (0.30 per m^2) compared to snorkel estimates (0.20 per m^2), while estimates were similar in riffles (Figure 8).

Water chemistry

Collection of water samples for chemical analysis began in July. Due to ongoing development of analytical techniques at the Seattle Public Utilities water quality laboratory, not all data collected since July has been analyzed (J. Dunn, personal communication). Table 17 summarizes water chemistry at selected sites on Fish Creek, Williams Creek, Steele Creek, Cedar River, and Rock Creek from November 2000 to February 2001.

Water chemistry of the mainstem Cedar and its tributaries was representative of oligotrophic waters in the Pacific Northwest (Welch et al. 1998). In general, concentrations of materials increased from upstream to downstream on the Cedar River. For example, alkalinity (mg/L $CaCO_3$) and electrical conductivity were lowest at CR 8, the most upstream site, and highest at CR 1, the most downstream site. Concentrations of dissolved phosphate-phosphorus and nitrate-nitrogen peaked at CR 4 immediately downstream of Taylor Creek. Interestingly, turbidity, which measures all particles (inorganic and organic), was higher at the most upstream site (CR 8) and declined downstream. Turbidity was very low (0.2 to 0.7) throughout the lower watershed. Temperature ranged from 4 to 6.3 °C, with the lowest (2.5 °C) temperature recorded at CR 7 and the highest (7.6 °C) temperature recorded at CR 2 and 4.

Fish Creek had the lowest recorded alkalinity and water temperature of all sites. The highest levels of dissolved phosphate-phosphorus and nitrate-nitrogen among all sites were measured at Taylor and Rock Creeks. Mean concentrations of phosphorus at TC 1 and 2 were 13 µg/L (range 11-16 µg/L), while mean nitrate-nitrogen concentration was 330 µg/L (range 100 – 340 µg/L). Concentrations of dissolved nitrate-nitrogen were much higher in Steele, Taylor, and Rock Creeks compared to other sites (i. e., Williams and Fish Creeks and Cedar River), especially at RC 1 (995 µg/L). The ratio of nitrogen to phosphorus (N:P) provides an indication of what element limits algal production (Welch et al. 1998). In general, N:P ratios (molar basis) less than 16:1 lead to nitrogen limitation. Ratios for the lower Cedar River watershed and its tributaries ranged from 31 (Fish Creek) to 184 (Steele Creek), which suggest that these systems are phosphorus-limited. Total organic carbon (TOC) was highest at the Rock Creek sites and at Williams Creek: mean TOC concentration at RC 1 was 1.9 mg/L, 1.2 mg/L at RC 2, and 1.5 mg/L at WC. No data were available for Fish Creek.

Stable isotopes

Samples to be analyzed for the stable isotopes of carbon and nitrogen were sent out the week of March 14, 2001 to the University of Georgia's Analytical Chemistry Laboratory. Data from these samples should be available later this spring.

Discussion

Habitat survey

In general, the Cedar River between Landsburg and Cedar Falls is a relatively confined reach with little instream wood. The lack of wood in the mainstem may be a result of large floods that occurred in the early 1990s, which transported much of the in channel woody debris downstream to Landsburg (D. Paige and D. Beedle, personal communication). Riffles and step-pools formed 65% of the total habitat of the Cedar River, while pools made up only 8%. The channel width per pool ratio ranged from 4.8 to 18, which is relatively high compared to that reported for other streams in western Washington. Montgomery et al. (1995) reported pool spacing of 0.2 to 10 (channel widths/pool) in stream reaches within the Tolt watershed that were approximately the same channel width as the Cedar. Pool spacing is sensitive to LDW, as others have found a negative correlation between pool spacing and LWD in streams (Beechie and Sibley 1998). We found no relationship between wood and pool spacing, possibly due to the low levels of woody debris providing low statistical power to detect any associations.

In western Washington streams with channel widths similar to the Cedar, Beechie and Sibley (1997) measured approximately 80-560 pieces of large woody debris pieces per linear kilometer. In contrast, the mean number of wood pieces per kilometer in the Cedar ranged from 16 (reach 8) to 88 (reach 6). Because wood is an integral component of the structure of streams in forested watersheds and profoundly affects the function of these ecosystems (Harmon et al. 1986, Bisson et al. 1987), the low levels of wood in the mainstem Cedar may potentially influence biological characteristics of the river. For example, woody debris is partially responsible for the retention of organic matter (Naiman and Sedell 1979, Bilby 1981) and sediment. Debris retained about 49% of the total stored sediment in seven Idaho streams (Megahan 1982) and approximately 87% in a New Hampshire stream (Bilby 1981). Furthermore, a number of studies have shown that salmonid abundance is positively correlated with wood debris (Fausch and Northcote 1992, Rosenfeld et al. 2000). Most salmonids require a diversity of habitat for various life history stages; the small amount of wood within the main channel of the Cedar may affect pool spacing and thus habitat diversity. Increasing the number of pools within the mainstem Cedar would likely increase the variance of channel structure, depth, and velocity, and thus the diversity of habitat available to salmonids (Montgomery et al. 1995). Thus, we suggest further study to evaluate the possibility of adding large woody debris to the mainstem Cedar. Such a restoration action would likely increase the complexity of river habitat, which may lead to increased production of resident salmonids, as well as increase the likelihood of successful colonization of anadromous salmonids after installation of the fish ladder at Landsburg.

In contrast to the mainstem, the relative proportion of riffles (33%) and pools (51%) in Rock Creek was more evenly distributed. Pool spacing (range 4.9 to 10 channel widths/pool) was slightly lower than the mainstem, but still higher than reported in other studies that examined physical habitat of streams of similar width and gradient (Montgomery et al. 1995, Beechie and Sibley 1997). Montgomery et al. (1995) found that pool spacing in streams of similar size to Rock Creek ranged from 0.7 to 3 (cw/pool). Pool spacing was lower in the lower reaches of Rock, especially in reach 1 (4.9 cw/pool) where total woody debris in the channel was particularly high (~350 pieces per km). Thus, the greater abundance of pools in this reach may be a result of the abundance of large wood in the channel. This reach is also characterized by relatively mature riparian vegetation, with a number of large western red cedars; therefore, we speculate that lower reaches of Rock Creek has a suitable source pool for woody debris recruitment.

Logistical constraints prevented us from determining the area of available habitat in the large beaver complex in reach 4 (upstream of intersection between road 40 and 41 and approximately 500 m upstream of where Rock crosses road 16). This area, and Rock Creek as a whole, may provide particularly good habitat for anadromous salmonids, especially coho salmon. Rosenfeld et al. (2000) observed the highest densities of anadromous cutthroat trout and coho salmon in small, low-gradient coastal streams on

Vancouver Island, British Columbia. Future work should include detailed habitat and fish sampling within this beaver complex.

Relatively short reaches of Taylor were habitat typed, as there is a barrier to anadromous fish close to its junction with the mainstem Cedar; therefore we will omit Taylor Creek from our discussion. However, we did survey a large portion of Williams Creek. This stream is steeper and smaller, and has fewer pools (18%) and more riffle (37%) than Rock Creek, especially in reach 1 and 3. Reach 2, however, had more pools (44%), and the lowest pool spacing (3.6) of any reach surveyed. This pool spacing is within the range identified by Montgomery et al. (1995) for small forest streams of western Washington. Williams Creek had an intermediate level of woody debris (more than the Cedar but less than Rock Creek), and was within the range of other small, forested streams (Bilby and Ward 1989, Montgomery et al. 1995, Beechie and Sibley 1997). Based on these characteristics, Williams Creek, especially the middle reach, may provide some suitable habitat for colonizing anadromous fish, particularly coho.

Fish populations

The trout population in the mainstem Cedar River was almost entirely made up of rainbow trout, while sites on Rock and Taylor Creeks were dominated by cutthroat trout. These trends in fish distribution agree with those reported in previous studies of the watershed (Cedar River HCP 1999). Cutthroat trout generally tend to occupy small tributary or headwater streams, while rainbow trout (or steelhead) are more common in mainstem areas or larger tributaries (e.g., Hartman and Gill 1968, Behnke 1992). This spatial separation, combined with temporal separation in spawning time, is believed to lead to reproductive isolation of some cutthroat and rainbow trout in coastal basins. Hybridization between cutthroat and rainbow trout (or steelhead), however, appears to be widespread along the Pacific coast (Johnson et al. 1999); factors such as the limitation of spawning habitat or the introduction of hatchery fish may result in increased hybridization (e.g., Henderson et al. 2000). There was some morphological evidence for hybridization between trout species in the Cedar; fin clips were taken from all captured individuals and are to be analyzed in the genetics lab at the Northwest Fisheries Science Center. These data may provide insights as to the degree of hybridization between rainbow and cutthroat within the mainstem and its tributaries. In our fish density estimates, we pooled abundance estimates for the two trout species.

Cutthroat trout are the least studied of the Pacific salmonids, and juvenile density estimates for fluvial populations are relatively rare (Johnson et al. 1999). The average total trout density in the Cedar was 0.06 fish/m^2, which falls at the extreme low end of the range of trout densities reported in other studies in the Pacific Northwest. Platts and McHenry (1988) estimated that the mean trout density in small streams in the Pacific Ecoregion was 0.29 fish/m^2; mean densities of cutthroat trout ranged from 0-2.5 fish/m^2. Estimates of cutthroat density in the Chehalis River basin (WA) ranged from 0.22 to 0.23 fish/m^2 (Johnson et al. 1999). Rosenfeld et al (2000) reported densities of cutthroat trout of 0.05 to 0.8 fish per m^2 in coastal streams of Vancouver Island, and Burns (1971) reported combined rainbow/cutthroat densities ranging from 0.09 to 1.63 fish/m^2 in northern California streams. Highest trout densities in the Cedar were observed in reaches 5, 6, and 9. The relatively high total densities in reach 5 and 6 may be related to the high densities of wood in these reaches. Rosenfeld et al. (2000) observed that abundance of cutthroat parr was positively related to woody debris. Thus, one possible reason for low densities of trout in the mainstem is a lack of woody debris, which creates structurally complex habitat such as scour pools.

Our data cannot determine what processes contribute to the low trout abundance, but we offer a number of potential hypotheses that should be considered in future studies. As mentioned above, low trout densities may be related to the relative lack of LWD and pools. Another possibility is inadequate spawning habitat due to reduced gravel recruitment to the stream because of the dam, or inadequate flows due to stream regulation. Predation is another factor that may be influencing fish densities. For example, we observed a number of birds that are known to eat fish, such as mergansers, kingfishers, American dippers, and osprey. In addition, predation by sculpins on juvenile trout may contribute to low salmonid densities. The low amount of wood in the mainstem may contribute to high predation rates, as wood provides important cover for stream fishes. In summary, there are a number of factors that may be limiting trout populations in the mainstem, and we suggest more detailed studies be performed to understand the factors that are most important.

Our data also show that larger fish were more abundant in pool and step-pool habitat. Rosenfeld et al. (2000) observed that larger cutthroat trout preferred pools, while fry densities were more evenly distributed among habitat types. In contrast to some other studies (e.g., Rosenfeld et al. 2000), we observed approximately double the number of trout fry in pool and step-pool habitat compared to riffles. Rosenfeld et al. (2000) hypothesized that higher densities of cutthroat fry in shallower habitat units (riffles, glides, etc) compared to pools may reflect the smaller three-dimensional spatial requirements of small fish. Alternatively, smaller cutthroat may have avoided pools in their study because of predation pressure from larger fish. Another possibility is the low density of fish in the mainstem may allow a greater overall proportion of fish to reside in the best available habitat. Although we have only a limited amount of data, our results suggest that the abundance of all size classes of trout was greater in pool habitats on the Cedar. Stream size is another factor that may explain patterns of fish density within and among streams. We observed a sharp decline in trout density with stream size. Similar patterns have been observed for cutthroat trout in Alaska (Murphy et al. 1996) and British Columbia (Rosenfeld et al. 2000). Rosenfeld et al. (2000) suggest that this pattern may be due to the fact that smaller streams have relatively more edge habitat and may provide more benign environments for spawning and rearing.

Water chemistry

In general, stream water in the lower watershed is low in dissolved material as evident by the low conductivity and turbidity. Conductivity is a measure of the ability of the water to carry an electrical current, and thus provides an estimate of total ionic potential. Conductivity ranged from a low of 28 µmhos/cm in Fish Creek to high of 57 µmhos/cm at Rock Creek (RC 2). The relatively high conductivity at RC 2 may be due to influence of the large beaver complex upstream of this site, which contributes additional sources of organic and inorganic matter to this site. Conductivity in the Cedar was lower than that reported for 22 streams in the Puget Sound lowland that were in watersheds with minimal urbanization (Bryant 1995 from Welch et al. 1998). Conductivity in eleven Cascade and four Olympic Mountain lakes averaged 9 and 57 µmhos/cm, respectively. Therefore, levels of ions in the Cedar River were similar to other relatively pristine to pristine waters of the Pacific Northwest. The low nutrient concentrations in the mainstem may also contribute to the low densities of resident salmonids. The lower Cedar may be particularly deprived of important nutrients and food because of the loss of marine-derived subsidies via decaying salmon carcasses.

Dissolved nutrients are also relatively low and are representative of conditions in other coastal streams and rivers. In reaches upstream of urban areas along the Skagit, Nooksack, and Stillaguamish Rivers, concentrations of dissolved nitrate and phosphate ranged from 130 to 410 and 13 to 30 μg/L, respectively (Welch et al. 1998). Dissolved nitrate concentrations in the Cedar and its tributaries (100 to 900 μg/L) were relatively similar to these other rivers except for high concentrations at RC 2 (900 μg/L). Dissolved phosphate concentrations in the mainstem Cedar (4 to 10 μg/L) were slightly lower than levels observed at these other rivers. The higher concentrations of dissolved nitrate in Steele, Rock, and Taylor Creeks and phosphate in Taylor and Rock Creeks compared to the mainstem was interesting and may be due to a number of factors such as the dam, underlying geology, riparian vegetation, biological processes or a combination of these factors. For example, we speculate that the higher levels of dissolved nutrients exported from these small streams were due to the greater abundance of deciduous riparian vegetation in these watersheds compared to the mainstem. The upper reaches of Rock Creek (i.e., upstream of RC 1) are dominated by red alder (P. Kiffney, personal observation). Red alder is a nitrogen-fixer and produces plentiful, nitrogen and phosphorus rich leaf litter (P.M. Kiffney, unpublished data). Other studies have observed streams lined with alder can have high concentrations of dissolved nitrogen compared to streams dominated by conifers (Wigington et al. 1998). Red alder leaf litter, therefore, may provide a significant source of limiting elements to terrestrial and aquatic ecosystems.

The higher concentrations of nutrients exported from the tributaries to the Cedar appear to subsidize the mainstem with important limiting elements. For example, Steele Creek has high levels of dissolved nitrate (500 μg/L), and dissolved nitrate in the mainstem increases from 100 μg/L upstream (CR 8) of Steele to 150 μg/L downstream of Steele (CR 7). A similar pattern is found above and below Taylor Creek, where dissolved nitrate and phosphate are higher at CR 4 (downstream of Taylor) compared to CR 5 (upstream).

Rivers are fundamental components of regional and global biogeochemical cycles, acting as both a transport pathway and sites of elemental transformations. Coastal rivers in the Pacific Northwest form a particularly dynamic link between the regions highly productive forests and nearby marine ecosystems. These preliminary data suggest that small streams in the lower Cedar watershed may provide an important transport pathway of important limiting elements to the mainstem Cedar, and thereby may be important controllers of ecosystem productivity. Further efforts should be addressed at understanding the variability in dissolved nutrient concentrations within the Cedar River watershed, as this may help drive restoration activities within the watershed. In addition, water chemistry of the Cedar River and its tributaries is typical of relatively pristine, oligotrophic, forested watersheds in the Pacific Northwest. Therefore, this watershed provides an excellent control or reference site to understand how various factors (climate, vegetation) affect surface water chemistry in the Puget Sound region.

These baseline data also suggest that trout densities in the mainstem are low. There are a number of factors that may be contributing to these low numbers, and we present a few possibilities. If restoration activities are to take place with the objective of increasing fish populations, we recommend that these actions be treated as experiments. This would entail collecting data (physical and biological) before any activity, such as adding wood, and monitoring for a number of years post-restoration. In this way, we can begin to assess how effective various management actions are in increasing resident and anadromous fish populations.

Summary

- The Cedar River mainstem between Landsburg and Cedar Falls had low amounts of wood compared to other systems of comparable size.
- Total trout densities in the mainstem were also low compared to other reported values. Low numbers of trout may be due to a number of factors such as habitat limitation (spawning gravel, woody debris) or predation.

- Water chemistry was similar to other oligotrophic waters in the Pacific Northwest. N:P ratios indicate the mainstem and tributaries are phosphorus-limited.
- Export of carbon, nitrogen, and phosphorus from Taylor and Rock Creeks to the mainstem was high. These streams may provide important materials fueling the Cedar River food webs.

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Table 1. Total area (m^2) and percent coverage of habitat types (not including side channels) within each reach on the Cedar River during summer 2000.

Reach	Flatwater	Pool	Riffle	Step Pool	Cascade	TOTAL
1	54215	1780	26595	0	0	82590
	0.66	0.02	0.32	0.00	0.00	
2	16805	1036	25869	8369	0	52079
	0.32	0.02	0.50	0.16	0.00	
3	8278	710	16389	34102	0	59479
	0.14	0.01	0.28	0.57	0.00	
4	5088	4021	6054	0	0	15163
	0.34	0.27	0.40	0.00	0.00	
5	6285	4671	16580	38737	0	66273
	0.09	0.07	0.25	0.58	0.00	
6	2193	4229	10831	13274	0	30527
	0.07	0.14	0.35	0.43	0.00	
7	2887	5632	9297	21213	0	39029
	0.07	0.14	0.24	0.54	0.00	
8	7205	8007	26968	6254	2310	50744
	0.14	0.15	0.53	0.12	0.05	
9	707	4320	2848	112	1488	9475
	0.07	0.45	0.30	0.01	0.16	
TOTAL	103663	34407	141431	122061	3798	405360
	0.26	0.08	0.35	0.30	0.01	

Table 2. Area (m^2) and percent coverage for habitat types (not including side channels) within each reach at Rock, Taylor, and Williams Creek during summer 2000 habitat survey.

Stream	Reach	Flatwater	Pool	Riffle	Step Pool	Cascade	TOTAL
Rock	1	474	956	2149	0	0	3579
		0.13	0.27	0.60	0.00	0.00	
	2	56	354	1339	0	0	1749
		0.03	0.20	0.77	0.00	0.00	
	3	1085	2734	3027	0	0	6846
		0.16	0.40	0.44	0.00	0.00	
	4	321	3837	1831	0	0	5989
		0.05	0.64	0.31	0.00	0.00	
	5	147	573	2191	0	0	2911
		0.05	0.20	0.75	0.00	0.00	
	6	355	755	3857	0	1927	6894
		0.05	0.11	0.56	0.00	0.28	
	TOTAL	2438	9209	14394	0	1927	27968
		0.09	0.33	0.51	0.00	0.07	
Taylor	1	0	397	1529	97	0	2023
		0.00	0.20	0.76	0.05	0.00	
	2	341	1578	6065	0	3171	11155
		0.03	0.14	0.54	0.00	0.28	
	TOTAL	2779	11184	21988	97	5098	41146
		0.07	0.27	0.53	0.00	0.12	
Williams	1	20	148	305	0	1125	1598
		0.01	0.09	0.19	0.00	0.70	
	2	0	133	169	0	0	302
		0.00	0.44	0.56	0.00	0.00	
	3	284	1355	2915	0	2739	7293
		0.04	0.19	0.40	0.00	0.38	
	TOTAL	304	1636	3389	0	3864	9193

	0.03	0.18	0.37	0.00	0.42

Table 3. Total number and frequency of occurrence of each habitat type (not including side channels) within each reach on the Cedar River mainstem during summer 2000.

Reach	Flatwater	Pool	Riffle	Step Pool	Cascade
1	15	16	15	0	0
	32.6	34.8	32.6	0	0
2	6	6	8	3	0
	26.1	26.1	34.8	13	0
3	4	5	2	4	0
	26.7	33.3	13.3	26.7	0
4	2	5	4	0	0
	18.2	45.5	36.4	0	0
5	2	5	6	3	0
	12.5	31.3	37.5	18.8	0
6	2	7	5	4	0
	11.1	38.9	27.8	22.2	0
7	4	15	9	6	0
	11.8	44.1	26.5	17.6	0
8	15	27	20	2	1
	23.1	41.5	30.8	3.1	1.5
9	3	9	6	1	2
	14.3	42.9	28.6	4.8	9.5
Total	53	95	75	23	3
	21.3	38.2	30.1	9.2	1.2

Table 4. Total number and frequency of occurrence of each habitat type within each reach of Rock, Taylor, and Williams Creeks during summer 2000.

Stream	Reach	Flatwater	Pool	Riffle	Step Pool	Cascade
Rock	1	9	29	23	0	0
		14.8	47.5	37.7	0	0
	2	1	10	9	0	0
		5	50	45	0	0
	3	13	45	41	0	0
		13.1	45.5	41.4	0	0
	4	5	30	22	0	0
		8.8	52.6	38.6	0	0
	5	7	46	35	0	0
		8	52.3	39.8	0	0
	6	23	96	72	0	30
		10.4	43.4	32.6	0	13.6
	TOTAL	58	256	202	0	30
		0.11	0.47	0.37	0.00	0.05
Taylor	1	0	4	2	2	0
		0	50	25	25	0
	2	2	16	16	0	8
		4.8	38.1	38.1	0	19
	TOTAL	2	20	18	2	8
		0.04	0.4	0.36	0.04	0.16
Williams	1	1	18	11	0	5
		2.9	51.4	31.4	0	14.3
	2	0	9	6	0	0
		0	60	40	0	0
	3	8	55	48	0	17
		6.2	42.6	37.2	0	13.2
	TOTAL	9	82	65	0	22
		0.05	0.46	0.37	0.00	0.12

Table 5. Mean number of main channel pools, side pools, and total pools per linear kilometer, and channel width per pool within each reach on the Cedar River mainstem during summer 2000.

Reach	Main channel pools/km	Side pools/km	Total Pools/km	Channel width/pool
1	0	4.7	4.7	9.7
2	0.5	2.7	3.3	11.6
3	0	2.1	2.1	17.9
4	5.2	3.4	8.6	4.8
5	1.3	0.8	2.1	16.6
6	2.2	3.0	5.2	8.3
7	3.7	4.2	7.9	6.7
8	2.3	7.9	10.2	5.7
9	9.0	1.0	10.0	10.1
Total	1.79	3.2	5.49	8.8

Table 6. Mean number of main channel pools, side pools, and total pools per linear kilometer, and channel width per pool within each reach on Rock, Taylor, and Williams Creeks during summer 2000.

Stream	Reach	Main channel pools/km	Side pools/km	Total pools/km	Channel width per pool
Rock	1	0.03	0.01	0.04	4.9
	2	0.02	0.00	0.03	7.1
	3	0.02	0.00	0.03	8.4
	4	0.02	0.00	0.02	10.2
	5	0.04	0.02	0.05	5.6
	6	0.03	0.01	0.04	9.3
	TOTAL	0.03	0.01	0.03	7.9
Taylor	1	0.01	0.00	0.02	5.6
	2	0.01	0.00	0.01	12.6
	TOTAL	0.01	0.00	0.01	11.1
Williams	1	0.02	0.01	0.03	10.2
	2	0.05	0.03	0.08	3.6
	3	0.02	0.00	0.02	14.7

TOTAL	0.02	0.01	0.03	12.4

Table 7. Mean number of large (LWD: $\geq$ 50 cm in diameter and $\geq$ 3 m long), medium (MWD: $\geq$ 20 cm in diameter and $\geq$ 2 m and $\leq$ 3 m long), and small (SWD $\geq$ 10 cm in diameter and $\geq$ 1 m and $\leq$ 2 m long) pieces of woody debris per kilometer in each habitat type at the Cedar River during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among habitat comparison.

Habitat type	*n*	LWD per km	MWD per km	SWD per km
Pool	31	14	27	32
Step Pool	23	20	34	32
Riffle	74	10	24	30
Flatwater	52	7	15	15
Cascade	3	15	5	15
Side channels	23	36	31	27
p-value		0.09	0.6	0.7

Table 8. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in each habitat type for Taylor Creek during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among habitat comparison.

Habitat type	*n*	LWD per km	MWD per km	SWD per km
Pool	20	29.0	62	64
Step Pool	2	90	128	80
Riffle	18	4	28	22
Flatwater	2	14	28	14
Cascade	8	30	53	63
Side channels	5	84	127	96
p-value		0.2	0.3	0.4

Table 9. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in each habitat type for Rock Creek during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among habitat comparison.

Habitat type	*n*	LWD per km	MWD per km	SWD per km
Pool	252	55 B	177	207 A
Step Pool	0	-	-	-
Riffle	200	23 B	967	91 AB
Flatwater	58	18 B	86	45 B
Cascade	30	132 A	135	147 AB
Side channels	46	24 B	90	77 B
p-values		0.0001	0.007	0.001

Table 10. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in each habitat type at Williams Creeks during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among habitat comparison.

Habitat type	*n*	LWD per km	MWD per km	SWD per km
Pool	80	54	98 A	86
Step Pool	0	-	-	-
Riffle	65	13	29 AB	39
Flatwater	9	12	13 B	52
Cascade	22	12	41 AB	68
Side channels	22	13	47 AB	84
p-value		0.1	0.02	0.5

Table 11. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in each reach at the Cedar River during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among reach comparison.

Reach	n	LWD per km	MWD per km	SWD per km
1	46	9	21	31
		B	BC	BC
2	23	23	47	44
		ABC	AB	ABC
3	15	6	11	16
		BC	C	C
4	11	19	22	15
		AB	BC	C
5	16	10	31	64
		BC	BC	AB
6	18	39	59	78
		A	A	A
7	34	11	23	22
		BC	BC	C
8	66	4	12	8
		C	C	C
9	21	12	18	17
		BC	C	B

Table 12. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in each reach for Rock, Taylor, and Williams Creeks during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among reach within stream comparison.

Stream	Reach	*n*	LWD per km	MWD per km	SWD per km
Rock	1	61	90	185.39	118
			A	AB	
	2	20	57	112.26	105
			AB	AB	
	3	96	51	107.87	102
			ABC	AB	
	4	55	50	174.23	178
			BC	AB	
	5	88	5	203.16	249
			C	A	
	6	220	40	94.91	118
			BC	B	
p-value			0.003	0.009	0.06
Taylor	1	8	41	63	49
	2	42	18	47	48
p-value			0.2	0.6	0.8
Williams	1	128	18	69	162
					A
	2	34	11	133	56
					B
	3	15	37	51	39
					B
p-value			0.5	0.09	0.0002

Table 13. Mean number of large, medium, and small (see Table 7 for size categories) pieces of woody debris in the Cedar River, and Rock, Taylor, and Williams Creeks during summer 2000. Mean values with the same letter within each wood category are not statistically different at a $p < 0.05$ for the among stream comparison.

Stream	*n*	LWD per km	MWD per km	SWD per km
Cedar	247	12	24	28
		B	B	B
Rock	540	43	134	142
		A	A	A
Taylor	50	22	49	47
		AB	B	B
Williams	177	31	61	64
		AB	B	B
p-value		0.001	0.0001	0.0001

Table 14. Mean (1SE) density of trout fry (< 80 mm total length), 1+ trout (> 80 mm < 120 mm), and 2+ trout (> 120 mm), and total density in each reach during snorkel surveys at the Cedar River, summer 2000.

Reach	*n*	Fry	1+	2+	Total density
1	15	0.025	0.002	0.007	0.034
		(0.04)	(0.006)	(0.016)	(0.05)
2	4	0.01	0.002	0.005	0.02
		(0.01)	(0.003)	(0.003)	(0.02)
3	5	0.02	0.005	0.004	0.02
		(0.01)	(0.004)	(0.005)	(0.02)
4	2	0.02	0.004	0.0005	0.02
		(0.02)	(0.001)	(0.0006)	(0.01)
5	7	0.04	0.01	0.02	0.07
		(0.03)	(0.01)	(0.02)	(0.04)
6	7	0.09	0.01	0.02	0.1
		(0.04)	(0.02)	(0.02)	(0.06)
7	7	0.02	0.02	0.03	0.07
		(0.03)	(0.04)	(0.07)	(0.1)
8	20	0.04	0.007	0.01	0.07
		(0.05)	(0.007)	(0.01)	(0.06)
9	6	0.08	0.02	0.04	0.13
		(0.05)	(0.01)	(0.02)	(0.08)

Table 15. Mean (1SE) density of trout fry (≤ 80 mm total length), 1+ trout (≥ 80 mm ≤ 120 mm), and 2+ trout (≥ 120 mm), and total density at each reach at Rock Creek (electroshocking) and Taylor Creek (snorkeling) during fish surveys, summer 2000.

Site	Reach	*n*	Fry	1+	2+	Total density
Rock Creek						
	1	5	0.02 (0.02)	0.02 (0.02)	0.04 (0.04)	0.08 (0.04)
	3	6	0.07 (0.03)	0.01 (0.01)	0.05 (0.04)	0.13 (0.06)
	5	3	0.1 (0.08)	0.04 (0.04)	0.30 (0.22)	0.4 (0.20)
	6	6	0.20 (0.10)	0.09 (0.07)	0.11 (0.13)	0.40 (0.30)
Taylor	1	4	0.02 (0.02)	0.002 (0.003)	0.03 (0.03)	0.04 (0.04)
	2	5	0.001 (0.01)	0.005 (0.005)	0.03 (0.03)	0.05 (0.04)

Table 16. Table. Mean (1SE) density of trout fry (≤ 80 mm total length), 1+ trout (≥ 80 mm ≤ 120 mm), and 2+ trout (≥ 120 mm), and total density in different habitat types at the Cedar River (snorkeling), Rock Creek (electroshocking) and Taylor Creek (snorkeling) during fish surveys, summer 2000.

Site	Habitat	*n*	Fry	1+	2+	Total density
Cedar River	Flatwater	19	0.03 0.04)	0.007 (0.009)	0.01 (0.01)	0.04 (0.05)
	Pool	32	0.06 (0.05)	0.01 (0.02)	0.02 (0.04)	0.09 (0.08)
	Riffle	16	0.02 (0.02)	0.002 (0.002)	0.003 (0.005)	0.03 (0.02)
	Step-pool	6	0.05 (0.05)	0.02 (0.02)	0.02 (0.02)	0.08 (0.09)
Rock Creek	Cascade	1	0.01	0.01	0.03	0.16
	Pool	13	0.14 (0.11)	0.07 (0.07)	0.08 (0.09)	0.30 (0.24)
	Riffle	6	0.07 (0.04)	0.02 (0.03)	0.04 (0.04)	0.12 (0.09)
Taylor Creek	Flatwater	1	0.006			0.006
	Pool	6	0.02 (0.02)	0.004 (0.005)	0.05 (0.03)	0.06 (0.03)
	Riffle	2	0	0.005 (0.007)	0.003 (0.004)	0.01 (0.01)

Table 17. Mean (minimum and maximum) values for water quality parameters measured at Cedar River (CR) mainstem sites, Rock Creek (RC), Taylor Creek (TC), Williams Creek (WC), Fish Creek (FC), and Steele Creek (SC) from November 2000 to February 2001.

	Alkalinity (mg/L $CaCO_3$)	Conductivity (µmhos/cm)	Turbidity (NTU)	Soluble reactive phosphorus (µg/L)	Nitrate + nitrite-nitrogen (µg/L)	Total organic carbon (mg/L)	pH	Temperature (°C)
CR 1	20	52	0.3	7	220	0.6	7.4	6.2
	(17-21)	(47-57)	(0.2-0.4)	(5-10)			(7.2-7.7)	(4.3-7.4)
CR 2	21	51	0.3	7	200	0.5	7.2	6.3
	(18-23)	(46-57)	(0.3-0.4)	(5-10)			(6.6-7.7)	(4.8-7.6)
CR 3	18	47	0.3	7	185	0.6	7.3	5.9
	(15-20)	(43-51)	(0.3-0.4)	(5-9)	(180-190)		(7.1-7.5)	(4.4-7.3)
CR 4	19	50	0.3	10	305	0.5	7.4	5.7
		(49-52)	(0.3-0.2)	(6-14)	(290-320)		(6.9-7.7)	(3.7-7.6)
CR 5	17	45	0.4	6	150	0.7	7.1	6.0
	(16-19)	(40-49)	(0.3-0.6)	(4-7)	(130-170)		(6.8-7.6)	(4.7-7.3)
CR 6	16	43	0.4	6	120	0.6	7.2	6.2
	(14- 18)	(39-46)	(0.3-0.7)	(4-7)			(6.9-7.6)	(4.8-7.3)
CR 7	10	30	0.6	4	155	0.9	7.3	4.1

	(10–11)	(29-31)	(0.5-1)	(3-5)	(110-200)		(7-7.5)	(2.5-5.4)
CR 8	10	29	0.7	4	100	0.9	7.8	4.0
	(9-11)	(29-31)	(0.5-0.8)	(3-5)			(7.1-8.1)	(2.7-5.4)
FC	9	28	0.3	8	110		7.5	3.4
	(9-10)	(27-28)	(0.2-0.3)	(7-9)			(7.2-7.7)	(1.3-5.0)
WC	10	40	0.2	9	102	1.5	7.1	4
	(8-12)	(38-44)	(0.2-0.3)	(8-11)			(6.8-7.5)	(2.5-5.8)
SC	12	40	0.3	6	500	0.9	7.2	4.5
	(11-13)	(37-43)	(0.2-0.5)	(5-7)	(450-540)		(7-7.9)	(3.2-6.2)
TC 1	19	51	0.2	13	330	0.5	7.3	5.1
	(18-20)	(50-55)		(11-16)	(100-340)		(6.3-7.7)	(3.4-6.2)
TC 2	19	51	0.2	13	330	0.6	7.1	5.1
	(18-21)	(50-55)	(0.2-0.3)	(11-16)	(100-340)		(6.4-7.5)	(3.5-6.2)
RC 1	12	48	0.3	14	995	1.2	7.1	4.5
	(11-15)	(45-52)	(0.2-0.3)	(13-15)	(910-1080)		(6.5-7.4)	(2.9-6.2)
RC 2	20	57	0.5	10	595	1.9	7.3	4.6
	(19-23)	(55-62)	(0.5-0.6)	(9-13)	(550-640)		(6.5-7.6)	(2.6-5.9)

Figure legend

Figure 1. Site map with habitat reaches on the Cedar River, and Rock, Williams, and Taylor Creeks.

Figure 2. Site map of water quality sampling stations along the Cedar River mainstem and its tributaries.

Figure 3. Mean density of different size classes of salmonids (primarily rainbow) and total density a) in each reach of the mainstem Cedar; and b) in each habitat type sampled. All density estimates were based on snorkel surveys.

Figure 4. Mean density of different size classes of salmonids (primarily cutthroat) and total density at Rock Creek a) in each reach; and b) in each habitat type sampled. Density estimates were from electroshocking.

Figure 5. Mean density of different size classes of salmonids (primarily cutthroat) and total density at Taylor Creek a) in each reach. Density estimates from both snorkel surveys and electroshocking are presented.

Figure 6. Mean density of different size classes of salmonids and total density for the Cedar River, Rock Creek, and Taylor Creek. Density estimates for both snorkel surveys and electroshocking are provided.

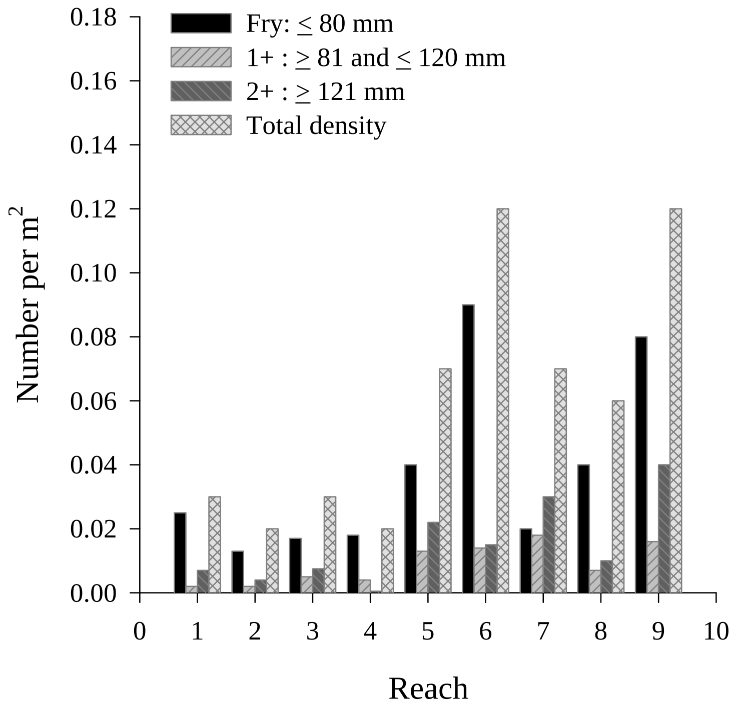
Figure 7. Fry and total trout densities as a function of stream width in the Cedar River and tributaries.

Figure 8. A comparison of salmonid density estimates from snorkel survey and electroshocking by a) reach and b) habitat type for the Cedar River.

Figure 9. A comparison of salmonid density estimates from snorkel survey and electroshocking by habitat type for Rock Creek.

Cedar River

Figure 3.



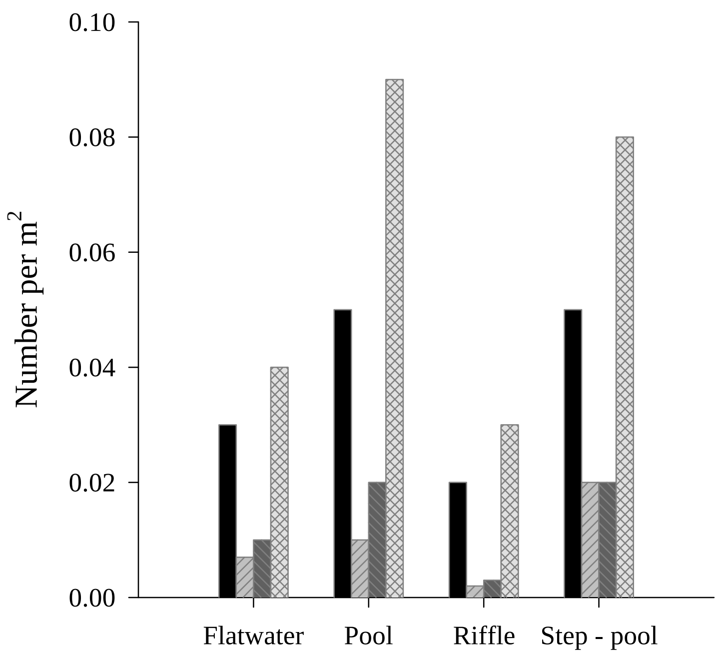
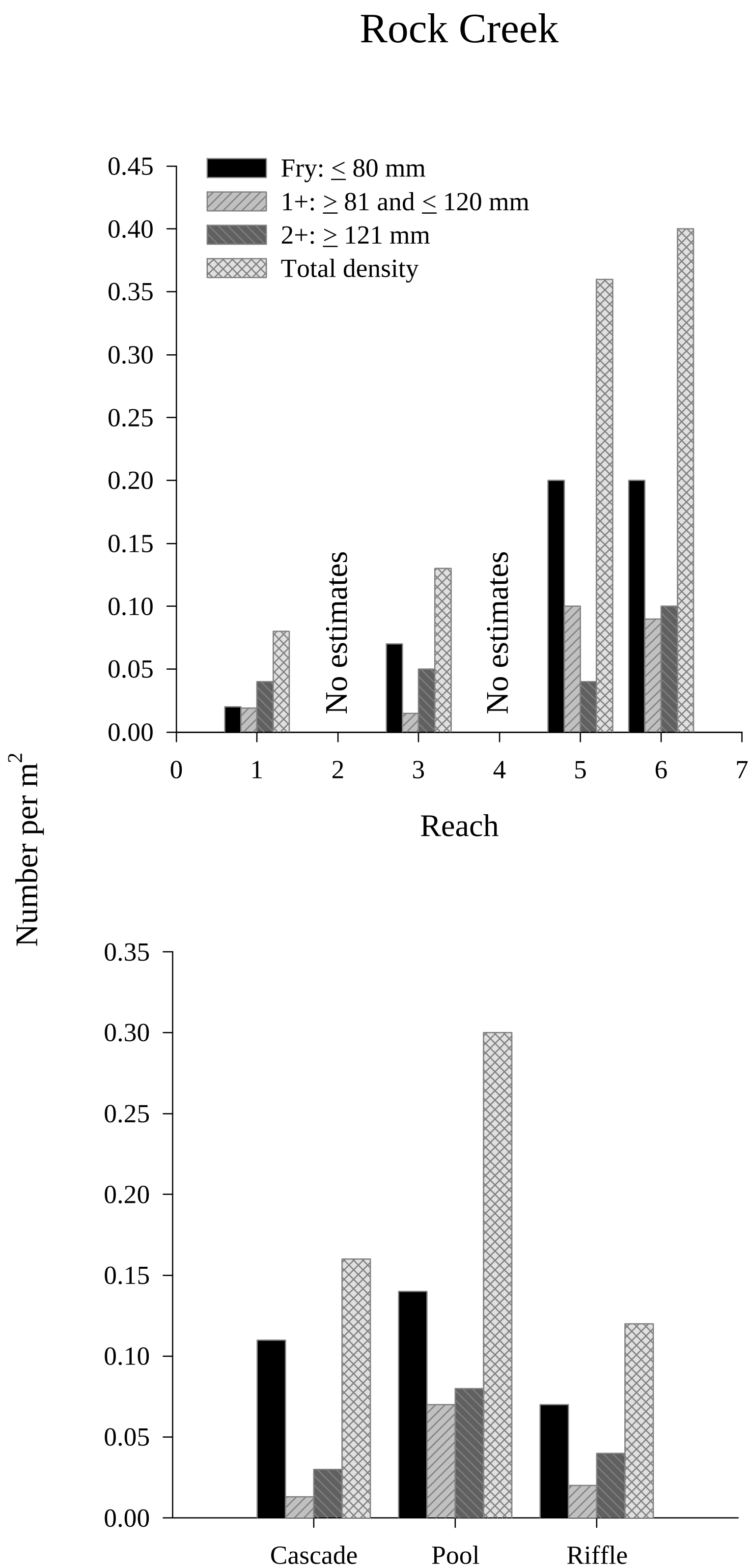


Figure 4.



Rock Creek
Fry: ≤ 80 mm
1+: ≥ 81 and ≤ 120 mm
2+: ≥ 121 mm
Total density
No estimates
No estimates
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
Reach
Number per m2
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Cascade
Pool
Riffle

Figure 5.

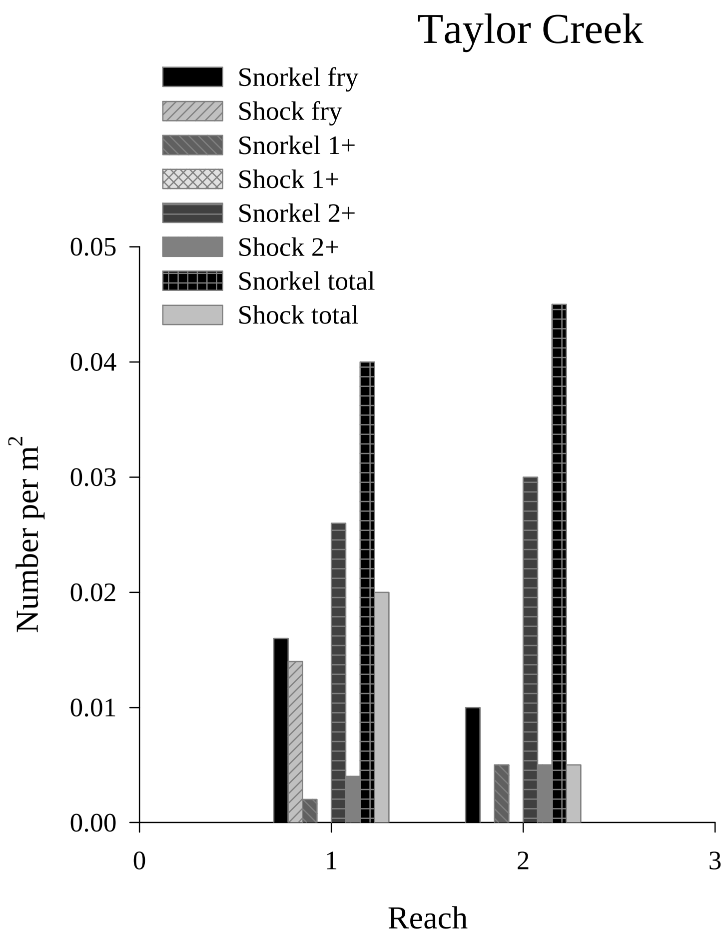

Taylor Creek
Snorkel fry
Shock fry
Snorkel 1+
Shock 1+
Snorkel 2+
Shock 2+
Snorkel total
Shock total
0.05
0.04
0.03
0.02
0.01
0.00
Number per m2
0
1
2
3
Reach

Figure 6.

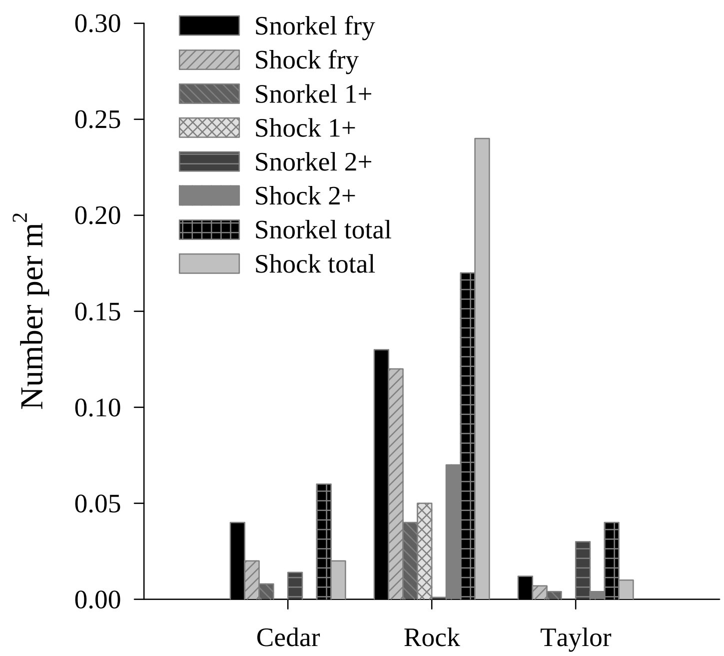
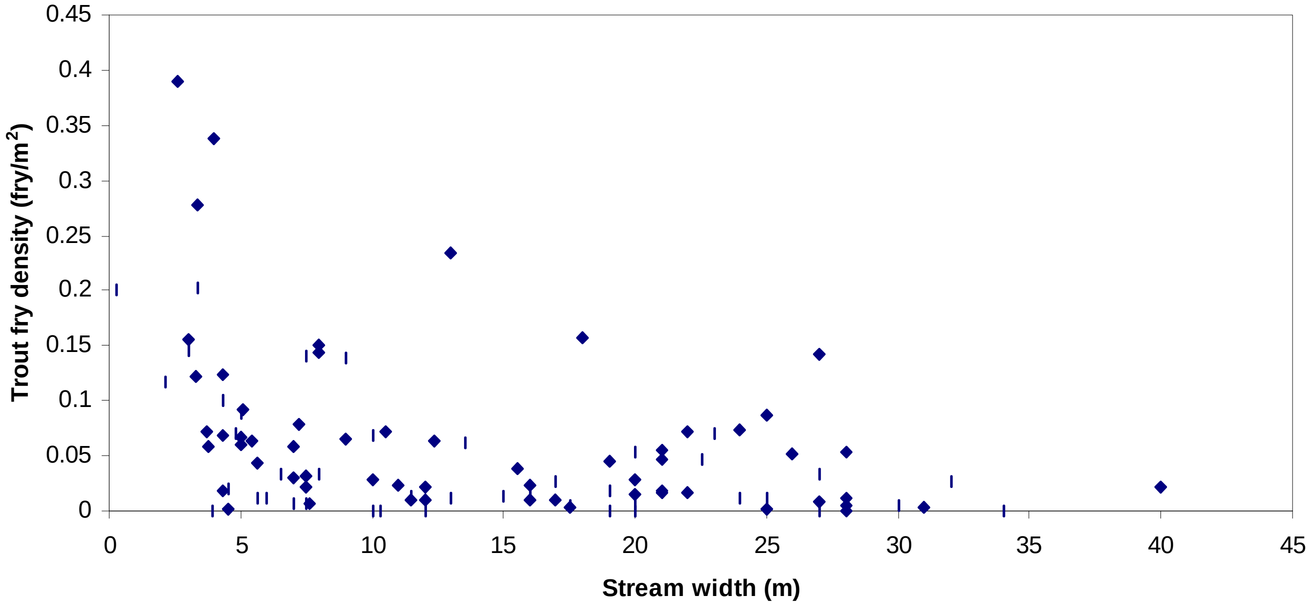

0.30
0.25
0.20
0.15
0.10
0.05
0.00
Number per m2
Snorkel fry
Shock fry
Snorkel 1+
Shock 1+
Snorkel 2+
Shock 2+
Snorkel total
Shock total
Cedar
Rock
Taylor

Figure 7


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Trout fry density (fry/m²)
0
5
10
15
20
25
30
35
40
45
Stream width (m)

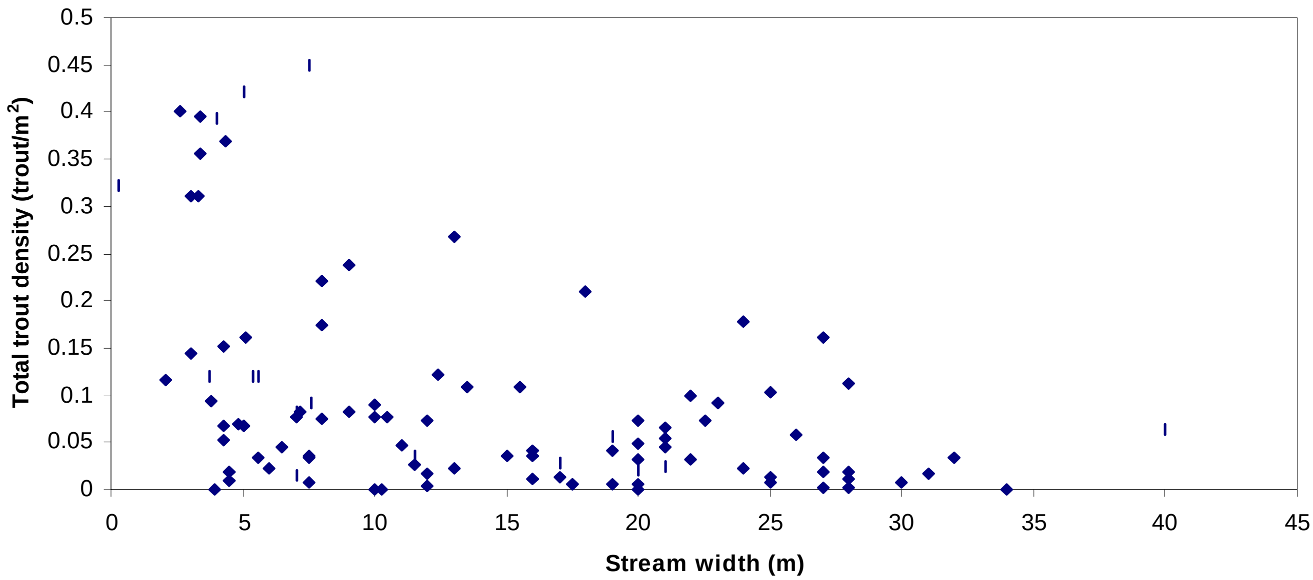
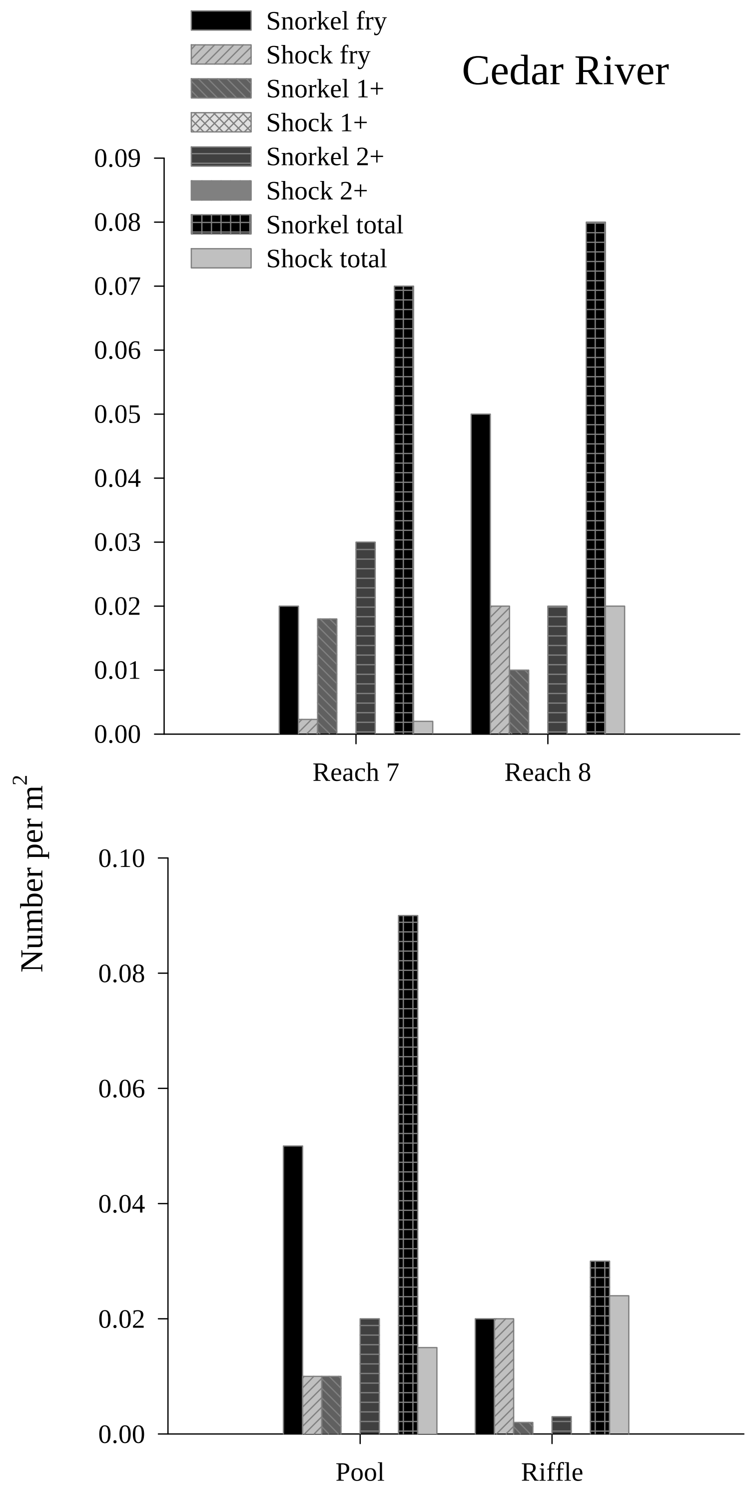
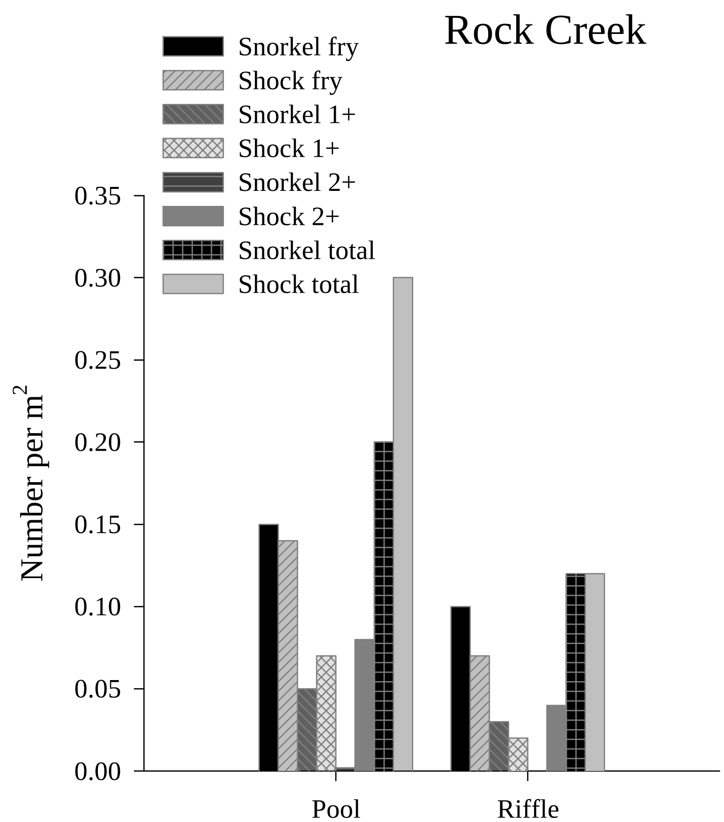

0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Total trout density (trout/m²)
0
5
10
15
20
25
30
35
40
45
Stream width (m)

Figure 8



Cedar River
Snorkel fry
Shock fry
Snorkel 1+
Shock 1+
Snorkel 2+
Shock 2+
Snorkel total
Shock total
Number per m2
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Reach 7
Reach 8
0.10
0.08
0.06
0.04
0.02
0.00
Pool
Riffle

Figure 9


Rock Creek
Snorkel fry
Shock fry
Snorkel 1+
Shock 1+
Snorkel 2+
Shock 2+
Snorkel total
Shock total
Number per m2
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Pool
Riffle

Appendix 1. List of reaches for the Cedar River, and their approximate locations and habitat features.

Reach	Location	Features
1	100 m upstream of boardwalk to RM 24.5	pool-riffle
2	RM 24.5 to RM 26	high gradient pool/riffle
3	RM 26 to 27.6	boulders; riffle/step-pool
4	RM 27.6 to RM 28.3	pool riffle
5	RM 28.3 to RM 29	boulders; step-pool/flatwater
6	RM 29 to RM 30	boulders; high gradient riffles/step-pools
7	RM 30 to RM 31.3	boulders; flatwater/pools/riffles
8	RM 31.3 to 33.5	flatwater/riffles
9	RM 33.5 to falls	confined channel; cascades/flatwater

Appendix 2. List of reaches for the Rock Creek and WilliamsCreek, and their approximate locations and habitat features.

Site	Reach	Location	Feature
Rock Creek	1	junction with Cedar to ~ 600 m upstream	pool/riffle
	2	~ extends 400 m upstream of reach 1	high gradient pool/riffle
	3	extends from reach 2 to road 40 and 41 intersection	pool/riffle
	4	upstream of 40/41 to 200 m upstream of road 16 crossing	beaver complex
	5	200 m upstream of road 16 crossing to 800 m upstream of road 10 crossing	high gradient; pool/riffle
	6	800 m upstream of road 10 to 600 m upstream of Kerriston Road	high gradient; riffle/cascade
Williams Creek	1	junction with mainstem Cedar to 500 m upstream	high gradient; cascade/riffle
	2	extends 600 m upstream of reach 2	low gradient; pool/riffle
	3	extends 1200 m upstream of reach 2 to headwater tribs	high gradient; cascades/riffles

Appendix 3. List of habitat units and types,; their length, width, and total area (m^2); and whether they were electroshocked or snorkeled during August and September 2000 fish survey.

Stream	Reach	Site Number	Habitat Type	Length	Mean Width	Area	Date Snorkeled	Date Electroshocked
Cedar	1	1	R				9/5/00	NA
Cedar	1	1.2	R				9/5/00	NA
Cedar	1	1	P				9/5/00	NA
Cedar	1	1	F				9/5/00	NA
Cedar	1	4	F	40	34	1360	8/24/00	NA
Cedar	1	5	R	77	36	2800	8/24/00	NA
Cedar	1	4	P	19	7	133	8/24/00	NA
Cedar	1	7	F	47	30	1421	8/24/00	NA
Cedar	1	6	P	18	7	121	8/24/00	NA
Cedar	1	6	R	40	25	1013	8/24/00	NA
Cedar	1	11	R	15	10	146	8/28/00	NA
Cedar	1	11.1	R				8/28/00	NA
Cedar	1	11	F	53	34	1790	8/28/00	NA
Cedar	1	7	P	21	13	263	8/28/00	NA
Cedar	1	15	R	54	31	1679	8/29/00	8/29/00
Cedar	1	2	S	18	9	154	8/29/00	8/29/00
Cedar	1	15	F	380	34	12920	8/29/00	NA
Cedar	1	15	P	12	5	60	8/29/00	NA
Cedar	1	17	P	10	8	80	8/29/00	NA
Cedar	2	19	R	45	29	1307	9/5/00	NA
Cedar	2	19.1	R	61	35	2159	9/5/00	NA
Cedar	2	1	SP	45	32	1434	9/5/00	NA
Cedar	2	3	S	18	4	68	9/5/00	NA
Cedar	2	20	R	38	38	1438	9/5/00	NA
Cedar	2	3	SP	30	32	960	9/6/00	NA
Cedar	2	3.1	SP	44	29	1288	9/6/00	NA

Cedar	2	3p1	SP	18	6	101	9/6/00	NA
Cedar	2	3p2	SP	17	10	175	9/6/00	NA
Cedar	3	22	F	98	27	2675	9/7/00	NA
Cedar	3	24	P	25	9	231	9/7/00	NA
Cedar	3	4	SP	24	33	810	9/7/00	NA
Cedar	3	24	R	50	27	1349	9/7/00	NA
Cedar	3	6	SP	40	33	1301	9/7/00	NA
Cedar	3	6.2	SP	21	7	144	9/7/00	NA
Cedar	3	6.3	SP	37	25	897	9/7/00	NA
Cedar	3	27	P	25	10	259	9/8/00	NA
Cedar	4	26	F	63	34	2144	9/8/00	NA
Cedar	4	30	P	42	9	384	9/8/00	NA
Cedar	4	27	F	71	27	1908	9/8/00	NA
Cedar	4	32	P	10	8	71	9/8/00	NA
Cedar	4	3	SC	44	7	322	9/8/00	NA
Cedar	5	37	P	52	24	1258	8/9/00	NA
Cedar	5	38	P	54	26	1418	8/9/00	NA
Cedar	5	39	P	14	8	117	8/10/00	NA
Cedar	5	31	F	87	34	2936	8/9/00	NA
Cedar	5	40	P	31	25	775	8/9/00	NA
Cedar	5	36	R	27	34	937	8/10/00	NA
Cedar	5	41	P	65	24	1550	8/9/00	NA
Cedar	6	32	F	62	24	1478	8/10/00	NA
Cedar	6	37	R	74	22	1610	8/10/00	NA
Cedar	6	5	S	86	6	478	8/10/00	NA
Cedar	6	42	P	42	12	504	8/10/00	NA
Cedar	6	33	F	66	17	1136	8/10/00	NA
Cedar	6	14	SP	22	17	383	8/31/00	NA
Cedar	6	40	R	50	26	1284	8/31/00	NA
Cedar	6	15	SP	58	19	1112	8/31/00	NA
Cedar	6	15.1	SP	53	21	1113	8/31/00	NA

Cedar	7	9 S	76	5	379	8/31/00	8/31/00
Cedar	7	49 P	46	28	1288	8/23/00	NA
Cedar	7	34 F	52	17	884	8/23/00	8/31/00
Cedar	7	50 P	9	5	45	8/23/00	NA
Cedar	7	45 R	95	18	1663	8/23/00	8/31/00
Cedar	7	46 R	56	21	1176	8/23/00	NA
Cedar	7	19 SP	278	23	6394	8/23/00	NA
Cedar	7	36 F	26	15	390	8/23/00	NA
Cedar	8	51 R	43	23	980	8/22/00	8/22/00
Cedar	8	39 F	36	19	672	8/22/00	8/22/00
Cedar	8	67 P	32	8	254	8/22/00	8/22/00
Cedar	8	69 P	9	20		8/22/00	NA
Cedar	8	70 P	47	21	991	8/17/00	NA
Cedar	8	44 F	41	23	912	8/17/00	NA
Cedar	8	45 F	31	22	663	8/17/00	NA
Cedar	8	72 P	21	18	387	8/30/00	8/30/00
Cedar	8	59 R	25	16	414	8/30/00	8/30/00
Cedar	8	73 P	36	19	676	8/30/00	NA
Cedar	8	46 F	53	14	744	8/30/00	NA
Cedar	8	74 P	33	6	210	8/30/00	NA
Cedar	8	74 P	27	10	253	8/8/00	NA
Cedar	8	75 P	52	6	308	8/30/00	NA
Cedar	8	75 P	121	21	2494	8/8/00	NA
Cedar	8	47 F	48	25	1209	8/8/00	NA
Cedar	8	78 P	21	9	184	8/8/00	NA
Cedar	8	64 R	37	19	703	8/8/00	NA
Cedar	8	48 F	35	11	401	8/8/00	NA
Cedar	8	81 P	39	13	492	8/8/00	NA
Cedar	8	66 R	35	12	426	8/8/00	8/17/00
Cedar	8	85 P	37	14	524	8/8/00	8/17/00
Cedar	8	91 P	45	13	560	8/23/00	NA

Cedar	8	53	F	22	11	252	8/23/00	NA
Cedar	8	93	P	33	10	321	8/23/00	NA
Cedar	8	95	P	83	17	1414	8/23/00	NA
Cedar	8	96	P	54	19	1010	8/23/00	NA
Cedar	8	99	P	19	9	176	8/23/00	NA
Rock	1	2	F	11	6	65	8/15/00	8/15/00
Rock	1	1	P	7	4	29	8/15/00	NA
Rock	1	2	P	11	4	43	8/15/00	8/15/00
Rock	1	4	P	16	6	87	8/15/00	8/15/00
Rock	3	16	F				8/16/00	NA
Rock	3	57	P				8/16/00	NA
Rock	3	59	P	18	5	88	8/16/00	8/16/00
Rock	3	51	R	13	7	90	8/16/00	8/16/00
Rock	3	64	P	10	5	57	8/16/00	8/16/00
Rock	3	54	R	13	3	41	8/16/00	8/16/00
Rock	3	65	P	16	5	79	8/16/00	8/16/00
Rock	3	55	R	20	4	85	8/16/00	8/16/00
Rock	5	121	P	18	5	82	8/18/00	8/18/00
Rock	5	101	R	6	4	26	8/18/00	8/18/00
Rock	5	122	P	11	3	36	8/18/00	8/21/00
Rock	6	225	P	7	4	25	8/21/00	8/21/00
Rock	6	6	C	23	3	76	8/21/00	8/21/00
Rock	6	226	P	5	3	13	8/21/00	8/21/00
Rock	6	170	R	8	3	20	8/21/00	8/21/00
Rock	6	7	P	6	3	16	8/21/00	8/21/00
Rock	6	229	P	7	4	25	8/21/00	8/21/00
Taylor	1	R1	R	23	12	282	9/11/00	9/11/00
Taylor	1	P1	P	9	10	89	9/11/00	NA
Taylor	1	P2	P	19	8	141	9/11/00	NA
Taylor	1	P3	P	14	10	140	9/11/00	NA
Taylor	2	F1	F	14	10	144	9/11/00	NA

Taylor	2 P8	P	7	4	28	9/11/00	NA
Taylor	2 P9	P	24	10	235	9/11/00	NA
Taylor	2 P10	P	30	8	238	9/11/00	9/11/00
Taylor	2 R9	R	23	8	193	9/11/00	NA

Appendix 4. List of water quality sites on the Cedar River mainstem and tributaries.

CR 1: upstream of 41 bridge; downstream of Rock Creek

CR 2: upstream of Rock Creek

CR 3: end of 40.1 road, approx. 1 mile downstream of Taylor

CR 4: 100 m downstream of Taylor

CR 5: upstream of Taylor Creek

CR 6: upstream of Williams Creek

CR 7: 100 m downstream of Steele CR 8: upstream of two major bridges the cross mainstem (i.e., near 50 road); and upstream of Steele Creek

CR 8: upstream of two bridges that cross Cedar River mainstem and upstream of Steele Creek.

FC: Fish Creek: control site above Cedar Falls

SC: at mouth of Steele

WC: at mouth of Williams

TC 1: upstream of fish barrier at USGS gauge

TC 2: at the mouth of Taylor

RC 1: at 10 bridge upstream of beaver complex

RC 2: mouth of Rock

Appendix 5. Pictures of different habitat types identified and surveyed for fish in the Cedar River and tributaries.